Recent Developments in the Relativistic Electrodynamics Controversy

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Abstract

In this paper we consider the controversial facets of two tests that are supposed to show experimental evidence against the accepted standard electrodynamics based on special relativity. The first refers to the detection of longitudinal electromagnetic forces in current carrying conductors, and the second represents a modified version of the Trouton-Noble experiment for which a non-null result has been found. Although the first test is inconclusive, the positive result of the second, if it is really such, is surprisingly in agreement with standard electrodynamics.

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1 - Introduction

Classical electrodynamics is in a slow but continuous evolution and some of the recent advances are the results of discussions that have been going on for decades. In recent times many papers have been published on themes related to the so called "electrodynamics controversy." This is a scientific controversy between physicists in favor of the standard relativistic interpretation of classical electrodynamics and physicists that favor an approach to electrodynamics based on coordinate transformations different from the Lorentz transformations and, thus, negate the validity of special relativity.

In this paper we consider, both from a theoretical and experimental point of view, two aspects of this ongoing controversy, namely: the detection of longitudinal forces on current elements [1-8] and an experiment of the Trouton-Noble type [10-16] which, supposedly, leads to a non-null result, in contrast to the traditional view exposed in many textbooks.

Before going into the details, we would like to make a general comment on the reliability of the papers that deal with this type of conflicting aspects of fundaments of physics. As it has been remarked by several epistemologists and experts in the philosophy of science, most physicists assume spontaneously a partial position in these discussions. The remark is that some experimentalists are tempted to, and in fact do, try to arrange the experimental set up in such a way that the data are trimmed or slightly modified in favor of expected or desired results, which would corroborate their own visions or theories. Moreover, it is not uncommon to find out that theoreticians may have selected from the existing theory formulas or partial approaches that lead to a theoretical result in agreement with their vision, most of the times neglecting "unintentionally" other formulas or approaches that would lead to opposite or different results.

We believe that the majority of physicists deal with controversial issues with serious and frank attitude, so that the effects of "unintentional" modification of experimental data and manipulation of theoretical models is probably limited and, hopefully, do not alter significantly the objective physical results. Nevertheless, some of these controversies, which generally imply the waste of a lot of time, would not subsist if physicists were a little more scrupulous in their research. Moreover, some physicists, either in favor the official, standard view of accepted theories or not, assume generally a rigid and dogmatic attitude that often prevents discussion and advances. Sometimes this attitude prevents the research of issues that later are recognized as real fundamental unsolved problems of modern physics.

With this in mind, we try to address in an objective way the two experimental topics mentioned above, being our impartiality somewhat assured because, although the predictions of opposing theories are clear, we are not completely in favor of the expected standard prediction.
Two groups of researchers performed recent experiments on these topics. The novelties of the experiments, which make them interesting from a theoretical point of view, are:

- In the case of detection of longitudinal forces, a time varying current has been used [3], unlike other previous experiments where the current was steady-state [1-2, 4-6].
- In the case of the Trouton-Noble experiment, the parallel plate capacitor was not shielded from external electric fields [13], unlike previous experiments of this type [10-12].

2 - Advances in the Controversy of the Longitudinal Forces on Current Elements

This is an old discussion that sets as opposing theories or formulas, describing the force acting a current element, the Ampere law and the Biot-Savart law.
The Ampere law reads

$$? F_{m,n} \; ? \; ? k \, \frac{i_m i_n dmdn}{(r_{m,n})^2}, \tag{1}$$

where i_m and i_n are the currents flowing in the current elements of length dm and dn respectively, r is the distance between the two elements, and k is a dimensionless geometrical function that takes into account the direction of current in each element.
An important feature of this law is that the action and reaction principle holds for the interaction between two current elements. Moreover, besides the usual forces perpendicular to the current elements, this law predicts also the existence of longitudinal forces, i.e. forces acting on a current element in the direction of the current.
The Biot-Savart law reads

$$? \mathbf{F}_{m,n} \; ? \; i_m d\mathbf{m} \; ? \; \mathbf{B}_n, \tag{2}$$

where $\boldsymbol{B}_m$ is the magnetic field due to current element dn, given by the Laplace formula

$$d\mathbf{B}_n \; ? \; \frac{?}{4?}(i_n d\mathbf{n}) \; ? \; \frac{\mathbf{r}_{n,m}}{(r_{n,m})^3}. \tag{3}$$

For this law, the forces are always perpendicular to the current element. However, this law does not comply with the action and reaction principle between two current elements. Nevertheless, both laws give the same result when the interaction is extended to the complete circuit and the action and reaction principle is not violated.
Several of the experiments that try to discriminate the two laws experimentally have been discussed in Ref. 4-5, 7. It has been remarked that the theoretical advantage of the Ampere law is that it complies with the action and reaction principle. Although some more refined discussion should be in order on this theoretical aspect, the final impression we have, from an experimental point of view, is that a point in favor of the Ampere law has not yet been made.
In this article we consider the results of a recent experiment by Graneau et al. [3] who claim to have proven the existence of electromagnetic longitudinal forces. Their experimental set up consists of a closed circuit where a high intensity time-dependent current I is induced, as

shown in schematically in Fig. 1. In this experiment, a capacitor is charged at a very high voltage and then discharged when connected to the electric circuit where a current I = I(t) is induced. A small section R of the circuit is isolated from the rest of the circuit by two air gaps, Gu and Gd, so that the rod R can move up and down if a net force acts on it in the longitudinal direction.

Graneau et al. observed that the rod moves, during their tests, and it reaches a height h that depends on the maximum intensity of the current and also on the difference between the lengths of the up and down gaps, Gu and Gd. Their data indicate that the net force, which makes the rod reach the height h, is zero for a symmetric set up, when Gu = Gd, while the force and the height h increases progressively up to a maximum value when, progressively, one sets Gd ? Gu.

Thus, Graneau et al. conclude that their experiment proves the existence of electromagnetic longitudinal forces and favor Ampere's law. An extended article refuting their conclusions has been recently submitted for publication [8]. Here we give some of the arguments used for the rebuttal and use this occasion to make some other comments about this controversy with the aim to provide suggestions for other tests of electrodynamics where time-dependent fields are used.

Qualitatively, our explanation of the results of Graneau et al. is the following. The net force exists but it is not of electromagnetic nature. When the current I of very high intensity is induced in the circuit, most of the power $P = RcI^2$ is dissipated via the Joule effect in the air gaps where the electrical resistance Rc is higher than in the rest of the circuit. The air in the gaps reaches a high temperature and pressure, generating a gas expansion, like a small explosion that acts on the inner surface of the mobile rod R.

However, the air in the smaller gap Gd is relatively more confined than the air in the upper gap Gu. Molecules, radiation energy, electrons, etc., of the expanding ionized air, will bounce back and forth many more times between the inner walls of the gap Gd than of Gu, before they leave the gap. Thus the pressure exerted in the smaller gap is more effective than that in the larger gap. It is this pressure difference that generates the net upward force that pushes the rod at a height h.

The details and a quantitative description of this mechanism are given in Ref. 8 where it is shown that the dependence of h with the length Gd is in good agreement with the experimental data and in better agreement with the the experimental results than the predictions of the Ampere law, as calculated by these authors. Thus, we believe that the experiment here considered is not conclusive and cannot be taken as an experimental proof of Ampere's law.

Some considerations are in order here that can help to address the controversy on what are the real forces acting on charges or current elements.

The novelty of this experiment is that it is conducted in non steady-state conditions, since the current varies with time. In this circumstance, the vector potential **A**(t), associated with the time varying current, also varies with time. Since **A**(t) can be in the direction of a current element, the force $-q\, d\mathbf{A}/dt = q\mathbf{E}$, where **E** is the induction electric field and q the charge associated to a current element, may also be in the direction of current elements.

Generally, the circuit is neutral so that besides the moving charge q there is also a stationary charge –q in the current element, and there should be no net force. But, if the rod R accumulates a net charge during the extreme conditions of the test, a longitudinal force could be acting on R, even though it is probably small in this set up.

However, the interesting point in the case of time-dependent fields is that one realizes that, contrary to the usual steady-state conditions where the Biot-Savart law is generally confirmed, there is no mention in the literature of experiments dedicated to the detection of forces acting on charges or current elements due to time-dependent induction fields.

When the phenomenon of induction is applied to a closed loop we have many direct verifications of the law of induction, or Faraday's law, in terms of the *emf*,

$$emf = \oint \mathrm{E} \cdot d\ell \,,$$

induced in the loop, which has an integral form. In this common case, there are forces acting in the direction of the current but only the resultant on the closed loop is being tested in terms of the induced current or voltage difference. The differential force acting on a current element or a part of a loop is not being tested in the usual induction experiments.

Thus, what has not been tested experimentally is not only if these induction forces are the same for charges at rest or in motion (as the moving charges in a current element), but if the induction forces act at all in an isolated stationary charge that is not part of a closed circuit.

One reason why the experimental results for the last mentioned case are not obvious, even for standard relativistic electrodynamics, is that the action and reaction principle does not hold for the interaction between a coil producing a time varying magnetic field and an isolated charge (this is the so called Shockley-James paradox, solved in Ref. 9). Theoretically, there should be a force $-q\, d\mathbf{A}/dt$ acting on the isolated charge. However, the existence of a possible reaction force on the coil has been the source of controversial discussions [9].

There is a pragmatic reason why these problems related to time-varying fields are mentioned here. From an operational point of view, it may be easier experimentally to detect possible discrepancies with classical electrodynamics for isolated static charges than current elements. In fact, a current element is mainly a theoretical concept that is difficult to realize experimentally, as all the objections and drawbacks of the experiments on longitudinal forces performed so far has shown. While an isolated charge is a theoretical concept realized experimentally in many set ups, such as the experimental proof of Coulomb law, and it should be easier to handle without ambiguities.

Thus, our suggestion and belief is that the electrodynamics controversy may achieve more interesting and definite results if it shifts its attention to the possible tests of electromagnetic interactions with time-dependent fields of the type mentioned above.

3 - A New Experiment of the Trouton-Noble Type

With the same spirit that motivated the mentioned papers [4] and [5], we believe that it is worth reconsidering here one of the tests of classical electrodynamics, the Trouton-Noble (TN) experiment, that has been recently discussed in the literature.

The outcome of the TN experiment has been considered a null result for decades. Trouton and Noble wanted to verify that a charge moving with respect to the ether frame where the Maxwell equations were valid, would create a magnetic field. In order to check this hypothesis, they suspended a charged capacitor to a thin thread. Since the Earth (and the capacitor) was supposed to be moving with respect to the frame of the ether, the magnetic field produced by one of the charges of the capacitor in motion would act, via the Lorentz force, on the other charge producing a torque and an observable rotation of the apparatus.

The experiment was first performed by TN [10] and later by Chase [11], and more recently and with a high sensitivity by Hayden [12]. The results of all these experiments indicate so far that the effect sought by TN does not exist.

However, recently Cornille [13] has claimed that he performed a TN experiment with positive result and gives a number of reasons why the previous experiments failed while his succeeded. This result is surprising because it seems to defy the generally accepted interpretation of the TN experiment and of the standard, relativistic interpretation of classical electrodynamics.

In the present section we show that a test of the Faraday law in differential form can be related to an experiment of the TN type. Furthermore, we clarify the experimental limits of the original TN experiment and of that performed by Cornille. In a future paper we consider another test of the Faraday law in differential form and point out an interesting and unique experimental consequence of the validity of the conservation laws in electrodynamics.

Without considering here Cornille's theoretical arguments in detail, we have noticed that Cornille's experimental set up differs from the others because he did not shield the suspended condenser from external electric fields. He also mentions that the magnetic field of the Earth cannot produce a torque because the charges of the capacitor are at rest in the laboratory frame of the Earth.

We show that, theoretically and contrarily to the current belief, in specific experimental conditions an experiment of the TN type, consisting of a suspended charged capacitor, may succeed. In fact, according to the standard interpretation of Faraday's law of induction, a positive result is theoretically possible if the effect of the small magnetic field of the Earth on the capacitor is taken into account.
However, the foreseen non-null result refers to the action of the external magnetic field of the Earth on the TN capacitor, which is actually rotating about the Earth axis in its diurnal rotational motion. It does not refer to the effect originally sought by TN and other theoretical effects considered by Cornille.

Furthermore, the experiment of the TN type here considered, may provide a definitive quantitative test of the old theory of magnetic field lines "cutting," which supposedly has been disproved qualitatively by the Kennard [14] experiment.

In the final part of the paper we indicate the experimental conditions that lead to a positive result for an experiment of the TN type and comment on the experimental result of Cornille.

4 - The Standard Description of the Faraday Disk

The Faraday disk, as shown in Fig. 2, consists of a conducting disk rotating about its symmetry axis and connected to an electric circuit AECR with one end (A) on the axis at the center of the disk and the other end (R) in the form of a sliding contact touching the external circumference. When a magnet is placed near the rotating disk with its magnetic pole aligned along the disk axis, an induction current flows in the circuit.

If the magnetic field **B** is uniform near the disk of radius *R* rotating with angular frequency ω, the electromotive force is given by

$$emf = \oint \boldsymbol{E}_i \cdot d\boldsymbol{l} = \oint (\boldsymbol{v} \times \boldsymbol{B}) \cdot dl = \frac{1}{2} \omega R^2 B \tag{4}$$

In many textbooks, result (4) is deduced from the integral form of Faraday's law taking into account the change of the magnetic flux as the material segment AR rotates in the presence of the field **B**. The integral form of Faraday's law cannot tell where, along AECR, the *emf* is induced.

However, considering Faraday's law in differential form, the expression $\mathbf{v} \times \mathbf{B}$ represents the induction, effective field $\mathbf{E}_i$ seen by the charges co-moving with the disk along the segment AR. It is a consequence of the validity of the Lorentz force $\mathbf{F}=\mathbf{E}+q\,\mathbf{v}\times\mathbf{B}$, written in a reference frame *S*, that indicates that the charge moving with velocity **v** in the presence of **B** and with $\mathbf{E}=0$, experiences the field $\mathbf{E}_i=\mathbf{F}/q=\mathbf{v}\times\mathbf{B}$.

According to the transformations of the electromagnetic fields of special relativity, an observer in a reference frame *S'* instantaneously co-moving with a point of the disk experiences the fields $\mathbf{B}' \approx \mathbf{B}$ and $\mathbf{E}' \approx \mathbf{v}\times\mathbf{B}$.

The observers of both frames *S* and *S'* agree that the *emf* is induced in the radial path of the disk and the description of the effect is essentially the same for *S* and *S'*. The same result is obtained if the magnet is rotating with the disk or if a rotating conducting magnet alone is used as a Faraday disk. In fact, according to the standard relativistic interpretation of electrodynamics a cylindrical magnet can be thought of as made of a cylindrical current distribution, and the current and field produced by the current is the same even if the current loops rotate about the symmetry axis.

Historically, the field lines of **B** were considered to have a precise physical reality. The potential difference generated across the radius AR was interpreted as due to the cutting of the magnetic field lines by the rotating metal. In the term $q\mathbf{v}?\mathbf{B}$, the velocity was interpreted as that of the charge with respect to the field lines, and not as the velocity of the charge relative to the reference frame where the magnetic field is measured.

In the case of a Faraday disk formed by a rotating magnet, in the pre-relativistic interpretation, Faraday's hypothesis of 1851 -- in which he visualized the magnetic lines as fixed to the magnet and rotating with it -- was assumed. In this case, the lines will thus be cut by the external branch ECR and the *emf* is not induced in the disk but instead in the stationary part ECR of the electric circuit. In this interpretation **v** represents the velocity of the "cutting" field lines at the position of the ECR.

Measurements of the induced voltage and/or current cannot discriminate between one theory or the other since in both cases the generated intensities are the same. In 1917 Kennard [14] achieved a breakthrough when he suppressed the ECR branch and was capable of measuring an induced potential difference along AR when the whole system rotated as a unit. Kennard's experiment consisted of a cylindrical capacitor and a coaxial solenoid. The induced electrostatic charge separation was measured by inserting an electrometer by means of two leads located along the axis. One of the lead was connected to the inner part of the capacitor, the other was connected to a radial wire reaching the outer part of the capacitor. When Tate [15] in 1922 reviewed the whole problem, he acknowledged Kennard's result and the implied disproof of the theory of rotating lines of force.

Without negating the validity of Kennard's experiment, we point out some of its limitations. First of all the apparatus consisted, as in the case of the Faraday disk, of two parts in relative motion: the measuring device, or electrometer, at rest; and the rotating capacitor in motion. What is being measured is always a potential difference between the two parts and not the local field. The inner part of the capacitor had finite dimensions and one cannot exclude that, if the flux lines are rotating, they may induce a potential difference in the stationary part of the electrometer. Furthermore, the results are necessarily qualitative because of the difficulties of graduating the electrometer and eliminating additional electrostatic effect due to the air drag produced by the rotating parts.

In an ideal experiment the measuring device should be co-moving with the rotating apparatus (magnet or solenoid) and measure the local electric field intensity, so that these objections no longer apply. This ideal situation is achieved with the set up of an experiment of the TN type that exploits the Earth rotation, as described in the sections below.

5 - The Effect of the Magnetic Field of the Earth

The magnetic field of the Earth (Fig. 3) is usually approximated by the equivalent field produced by a magnetic dipole placed at the center of the Earth of intensity $\mathbf{m}_o$=8.1?10^{25} gauss?cm^3. Correspondingly, the magnetic field on the surface of the Earth varies from 0.3 to 0.6 gauss depending on the latitude.

The magnetic dipole is not aligned with the axis of rotation with which it forms an angle ? ?14$^?$, corresponding to a distance of about 1000 miles between the geographic and the magnetic pole. The radial component $m_o$sin? is quite smaller than the axial component $m_o$cos?, being sin?/cos? ? 0.22. In the following we consider first the effect of axial component and then show that, for our purposes, the radial component has no effect and can be neglected.

Let us consider the component aligned with the Earth axis with a dipole moment intensity of $m=m_o\cos?$. To all respects, the Earth can be considered equivalent to a rotating magnet so that the results of Sec. 2 valid for the Faraday disk can be applied here.

What is of interest here are the perpendicular and tangential components of **B** to the Earth surface. Taking the *z*-axis of frame *S* aligned with **m**, the components of the field **B** at a given latitude and longitude of the vector **r** are given by

$$\mathrm{B} \; ? \; \frac{3\,\mathrm{r}\,?\mathrm{r}?\mathrm{m}\,?}{|r|^5} \; ? \; \frac{\mathrm{m}}{|r|^3} \tag{5}$$

By means of Eq. (5), one can find the field components that, because of the symmetry, do not depend on the longitudinal or azimuthal angle f, but depend on the latitude *?* . In analogy with the interpretation of the Faraday disk, a charge fixed on the Earth and rotating with it in the presence of the field **B** will feel the effective electric field $\mathbf{E}_i$.=**F**/*q*=**v**? **B**.

We consider now the effect of the small radial component $m_r=m_o\sin?$ of the magnetic dipole. In the rest frame *S*, the radial component $\mathbf{m}_r$ rotates with angular velocity ? . At a point **r** in space the magnetic field due to $\mathbf{m}_r$ is a time-varying field and, by Maxwell's equations there must be also an induction electric field. In order to find this electric field, one can consider a moving inertial reference frame *S'* instantaneously at rest with a point rotating with the same angular velocity ? . We use special relativity but neglect retardation effects and relativistic corrections of order higher than *v/c*. In *S'* the magnetic field $\mathbf{B}_r$´? $\mathbf{B}_r$ produced by $\mathbf{m}_r$ is constant and there is no electric field. Transforming the fields one finds that the electric field in *S* is given by -**v**?$\mathbf{B}_r$. The Lorentz force due to $\mathbf{m}_r$ acting on a charge fixed on the rotating Earth, is **F**=*q***E**+*q***v**? $\mathbf{B}_r$ =*q*(-**v**? $\mathbf{B}_r$+ **v** ?$\mathbf{B}_r$)=0. Thus, the radial component $\mathbf{m}_r$ does not have a net effect on a charge at rest on the Earth.

The main difference between the effect of **m** and $\mathbf{m}_r$, is that **m** generates a constant magnetic field in *S*, while $\mathbf{m}_r$ generates a constant magnetic field in *S'*.

In conclusion, a charge fixed on the rotating Earth feels only the effect of the field **B** due to **m**, i.e. it experiments a field $\mathbf{E}_i$.=**F**/*q*=**v**? **B**.

6 - An Experiment of the Trouton-Noble Type in the Magnetic Field of the Earth

Let us consider now a charged capacitor suspended by a thin elastic thread of torsion constant *k* as in the case of the Trouton-Noble experiment. The capacitor is generally described as two charges of opposite value *q* placed at the ends of an insulating rod and separated by a distance *d*, as shown in Fig. 4.

In the following we assume the standard interpretation of electrodynamics which foresees a null result for the effect sought originally by Trouton and Noble. This was supposed to be a torque due to the self-action of the charges moving in the ether and generating a magnetic field with their motion.

What we look for in the present experiment is the effect of the external magnetic field of the Earth on the moving charges. As discussed in the section on the Faraday disk, in the frame *S* the sought effect is due to the Lorentz force *q***v**? **B**, in the frame co-moving with the charge the effect is due to the existence of the electric field *q***v**? **B**. In order to detect this electric field, shielding screens around the capacitor must be avoided, as in the case of Cornille's experimental set up.

With respect to frame *S*, the velocity **v** of the charges is in the West to East direction. The only torque on the capacitor about the axis of suspension is due to the component B_p of the magnetic field perpendicular to the Earth surface that produces a force $F=qvB_p$ lying on the plane of **v** and **d**, tangent to the Earth. The resulting torque is

$$? ? \left(\mathbf{r} ? \left(q\mathbf{v} ? \mathbf{B}_p\right)\right) ? qvB_p dcos? \;,$$

where ? is the angle formed by the vectors **v** and **d**.

This torque generates a rotation of the capacitor that tends to set **d** perpendicular to **v**. At the position of equilibrium the capacitor has rotated by an angle ? such that $?=k?$. In order to verify that this angle is detectable with an apparatus of the Trouton-Noble type, we express the charge on the capacitor, for a parallel-plate capacitor, as $q=CV$ and $C=?_o S/d$. The result is that, when cos? = 1,

$$? ? \frac{?_o SV\left(vB_p\right)}{k} \;. \tag{6}$$

In order to estimate ?, we consider a location near the equator where the tangential velocity is greater, for example in Venezuela at $8^?$ above the equator corresponding to $?=82^?$ in Eq. (5´). In this case, with the radius of the Earth given by $r=6.37?10^6 m$ and a velocity of $v=?rsin?=445$m/sec near the Equator, the perpendicular field component turns out to be $B_p=0.17$gauss directed toward the centre of the Earth and $E_i=v?B? 7.5?10^{-3}$V/m. With a potential difference of $V=2?10^4$Volt, a plate surface $S=1\mathrm{m}^2$ and a torsion constant $k=10^{-8}\mathrm{kg?m^2/s^2}$, the torsion angle turns out to be of the order of $??0.13$ radians$?7.5^?$, which is easily observable.

7 - Conclusions

We have considered two aspects of the electrodynamics controversy.

The first aspect refers to the detection of longitudinal forces acting on current elements. We discuss the experiments by Graneau et al. and point out some weakness in the experimental set up that make it unreliable for this test.

However, an interesting feature of the experiment performed by Graneau et al. is that time-dependent fields have been used. This feature reminds us that there are no tests of the elementary laws on charges and current elements and that Faraday's law of induction has been tested with great accuracy but only in its integral form, on closed loops.

Consequently, our suggestion is that the electrodynamics controversy should be directed toward testing the elementary forces relevant to the discussions on the Shockley and James paradox.

The second aspect refers again to the test of the Faraday law in differential form. We have shown that the effects of the magnetization produced by the rotating Earth can be described in analogy with those produced by a rotating magnet. Thus, an apparatus of the TN type should lead to a non-null result and can be used to detect the small induction electric field $\boldsymbol{E}_i=\boldsymbol{v}?\boldsymbol{B}$ seen by an observer at rest on the Earth surface and co-moving with it in its diurnal rotational motion with a tangential velocity $\mathbf{v}=??\mathbf{r}$.

This induction electric field is analogous to the local field supposed to be generating the *emf* observed in a closed electrical circuit in the Faraday disk. Therefore, this experiment can be used as a test of the Faraday law in differential form and as a quantitative test for the localization of the *emf*, which has been already qualitatively verified by Kennard.

The non-null result reported by Cornille for his TN experiment -- with a high voltage of $40?10^3$V -- seems to corroborate the existence of the small induction electric field $\mathbf{E}_i$ However, there are still some difficulties.

First of all, Cornille's result is qualitative, as he observed a rotation of the apparatus tending to align along the velocity **v**, but did not measure the torque. He also states that the rotation is unchanged by reversing the potential difference and concludes that the TN effect exists. If we discard the existence of the effect originally sought by Trouton and Noble, an explanation of the effect observed by Cornille can be attributed to an electrostatic induction of objects near the capacitor, which does not depend on the sign of the potential difference.

In conclusion the experimental evidence for the localization of the *emf* is still uncertain and at most qualitative. However, the experiment described in this paper represents a theoretical improvement and its realization should be able to settle the question of localization -- and the questions raised by Cornille's experiment -- in a quantitative and definite way.

Acknowledgments

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Figure Captions

Fig. 1. Scheme of the electrical circuit used by Graneau et al. for the detection of longitudinal electromagnetic forces. The mobile part of the circuit R moves up when a strong, impulsive electric current flows.

Fig. 2. Scheme of the Faraday disk picturing the magnetic flux lines generated by the magnet. In the Faraday disk the *emf* is induced along the rotating material segment AR of the circuit.

Fig. 3. Scheme of the magnetic field lines of the Earth. The Earth magnetization can be represented by a magnetic dipole placed at the centre of the Earth.

Fig. 4. A Trouton-Noble apparatus is suspended to a thin elastic thread. Due to the rotational motion of the Earth, the charged condenser moves with velocity **v** in the presence of the external magnetic field **B**. The Lorentz force **F**=*q***v**?**B** acts on the charges ?*q* and tends to rotate the condenser until **d** is perpendicular to **v**.

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FIG. 1

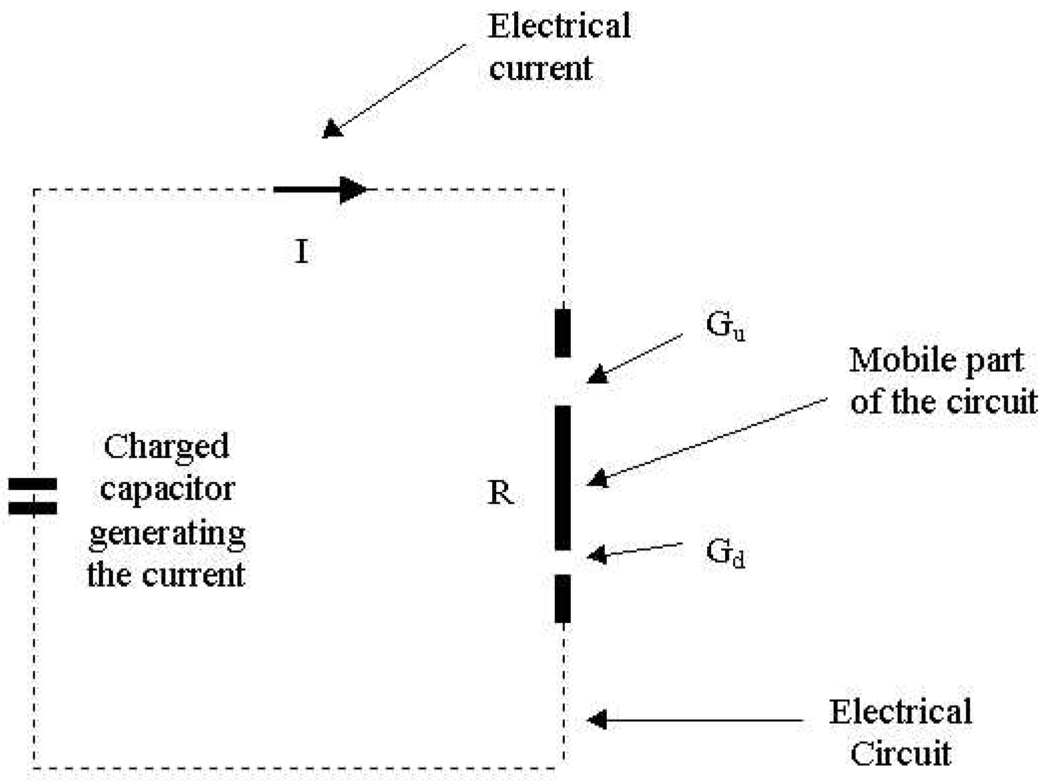


FIG. 2

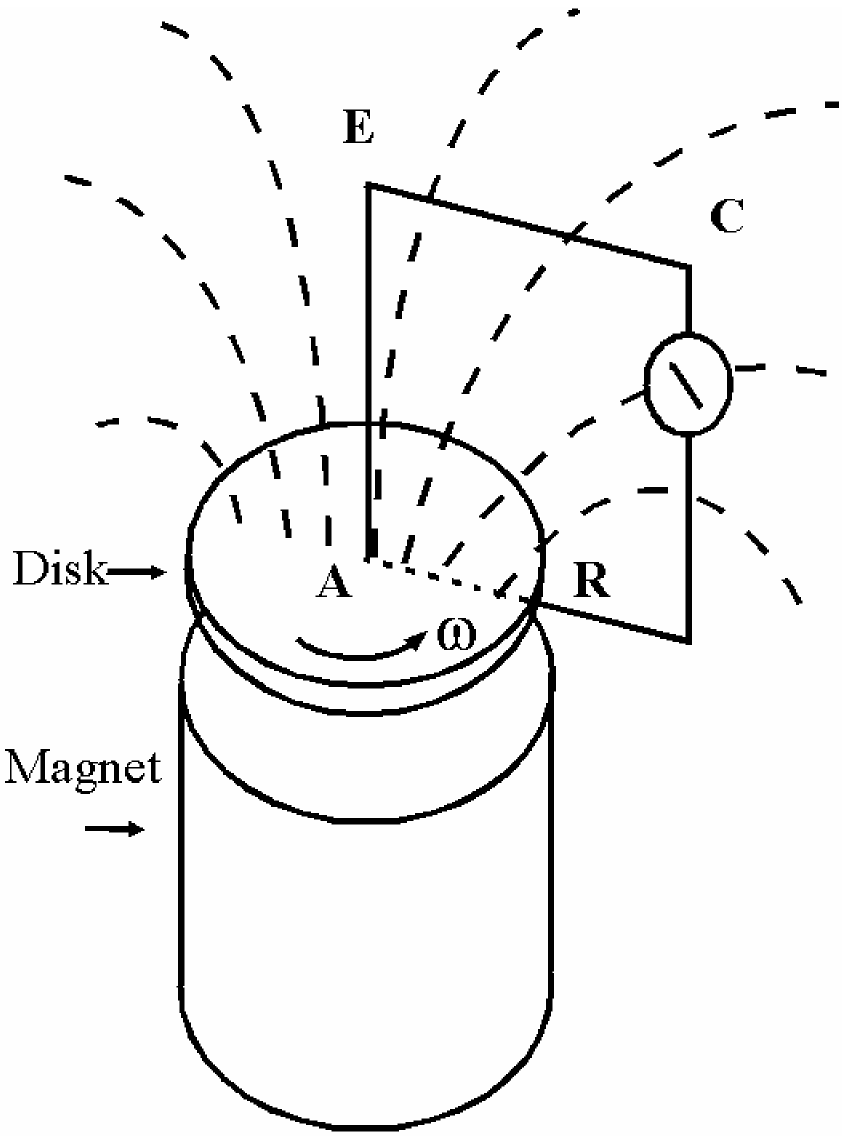


FIG. 3

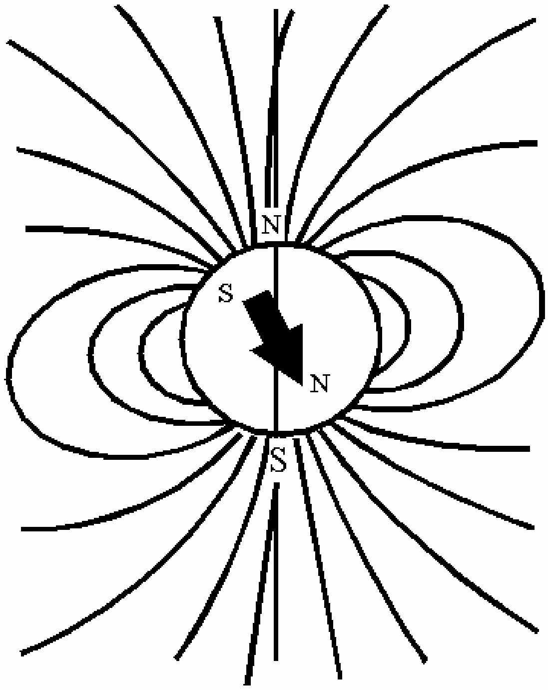
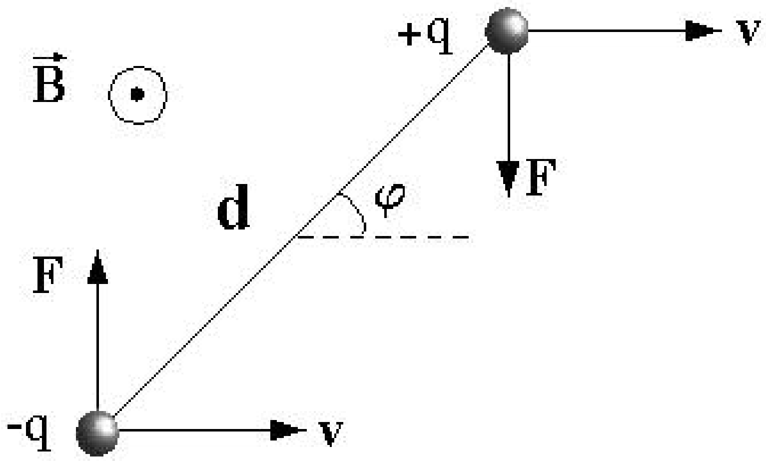


FIG. 4



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[A presentation of the first two authors can be found in *Episteme* N. 3]